ADJACENCY-BLURRING-EFFECT OF SCENES MODELED BY THE RADIOSITY METHOD

by

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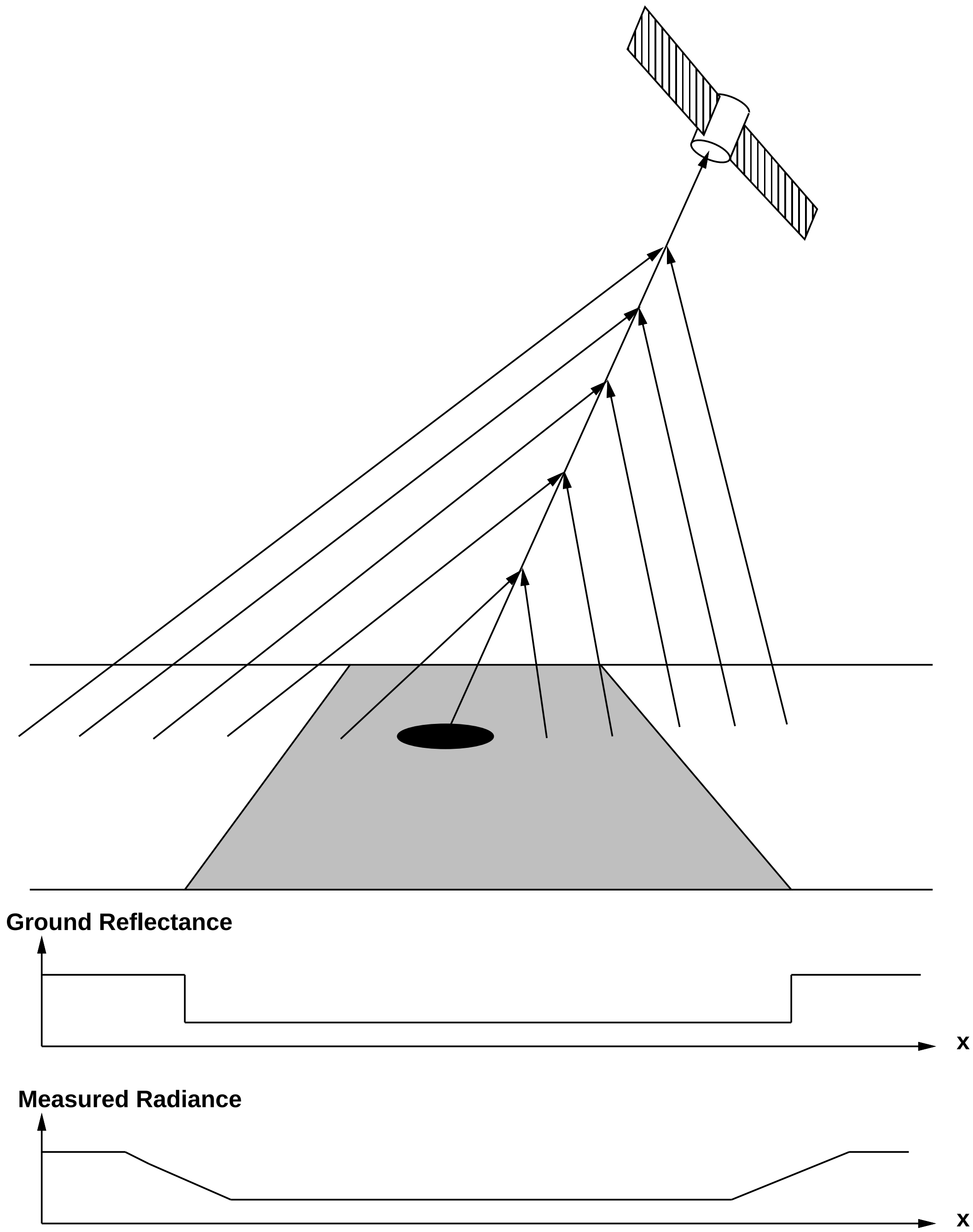
Content



Adjacency-blurring-effect over a discontinuity of reflectances

Adjacency-Blurring-Effect

Effects on sensor performance :

- Borders between bright and dark surfaces blurred

- Errors in the detection and classification of small bright targets surrounded by a dark region or dark targets on a bright background

- Reduction of contrast

How can we model the adjacency-blurring effect ?

- Point Spread Function (PSF)

- (Blurred scene) $=$ (unblurred scene) $\otimes$ PSF

Methods to calculate PSF's :

- Radiative transfer calculations
- Monte Carlo simulations

Properties of PSF's :

- Rotationally symmetric for nadir views if surface Lambertian
- Mirror symmetric for oblique views if surface Lambertian
- Asymmetric for any view direction if surface in non-Lambertian

Computing the Point Spread Function for Lambertian Surfaces

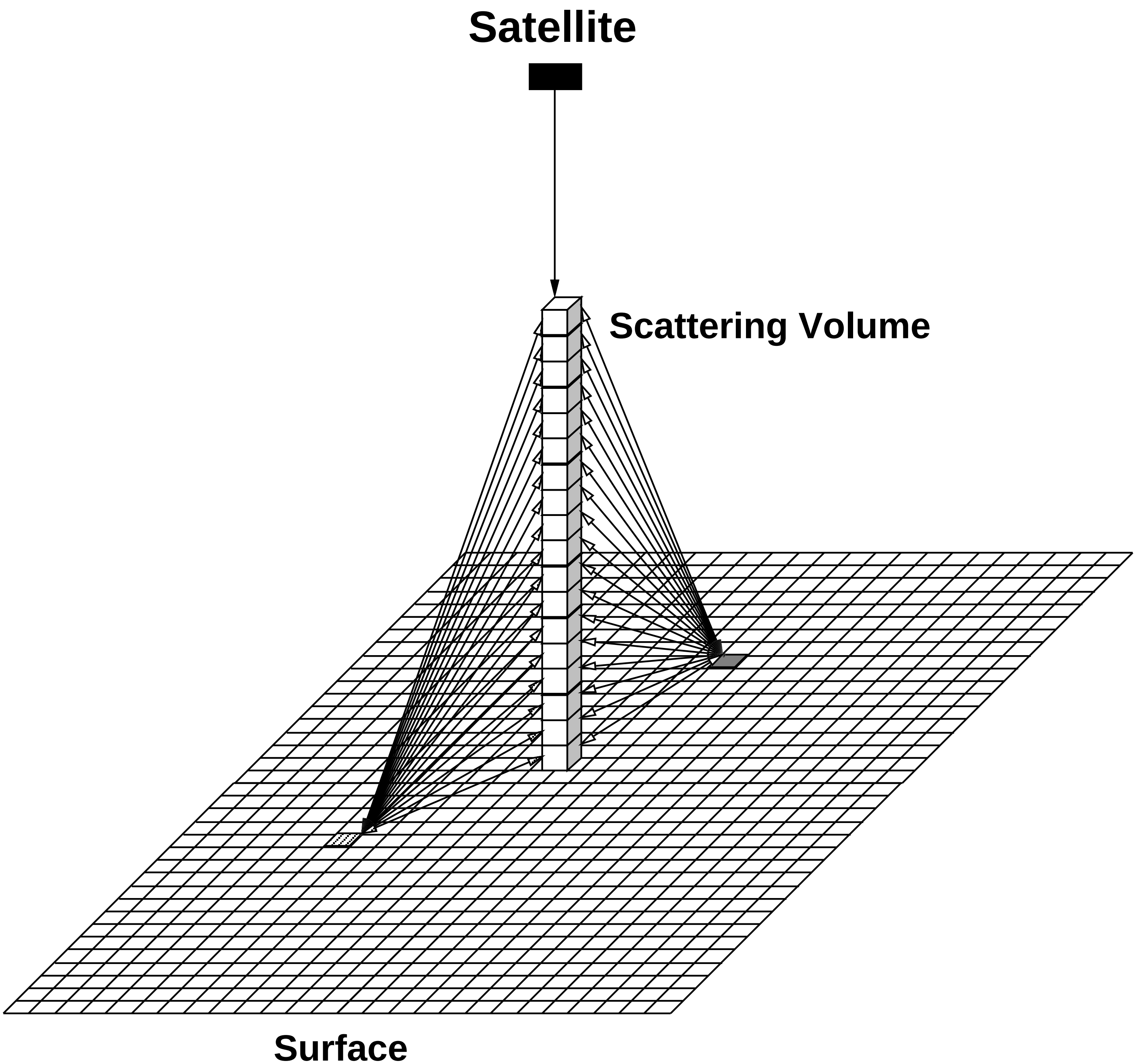
Definition:

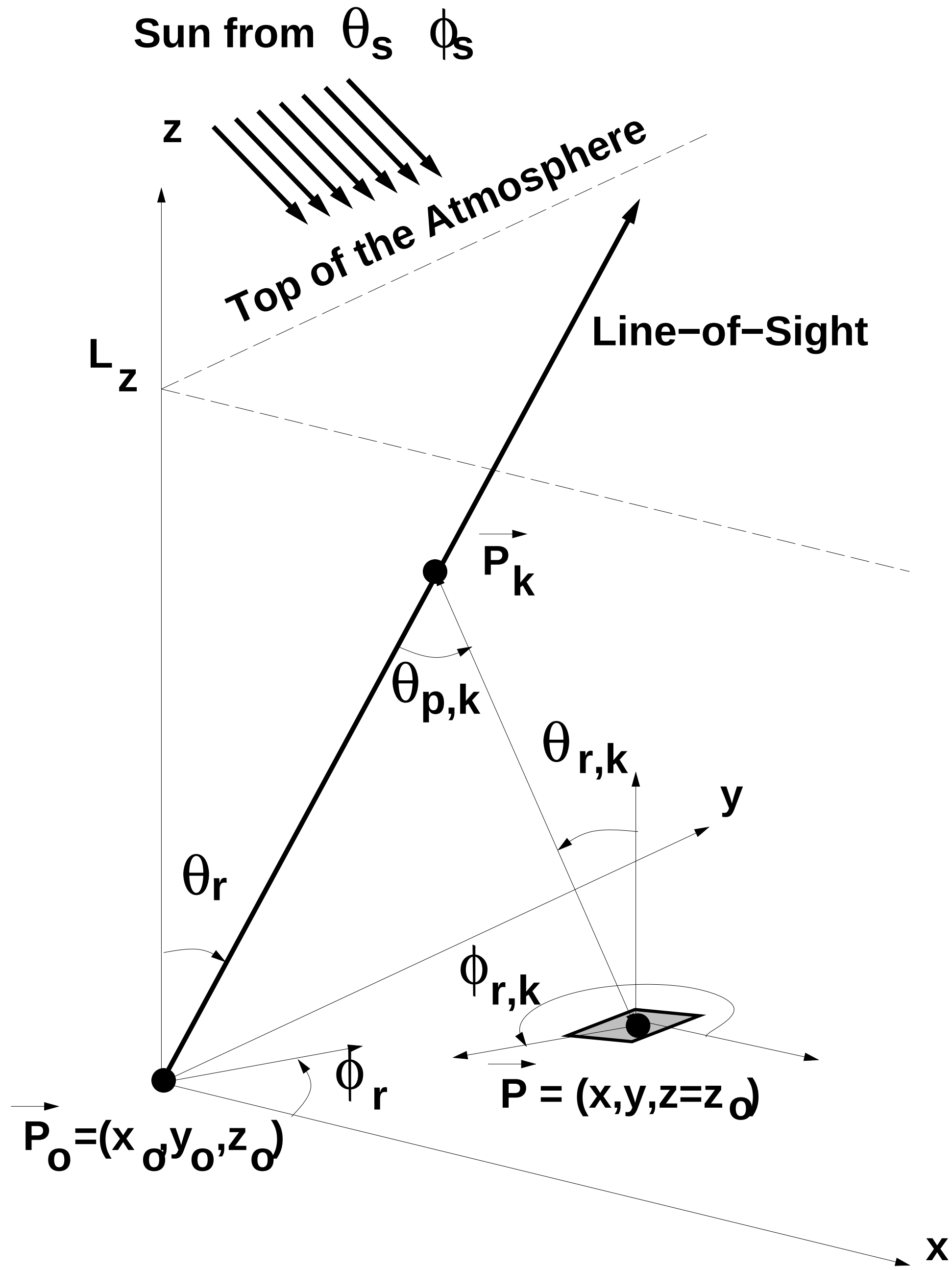
The point spread function :

$$PSF(x, y, z; x_0, y_0, z_0; \theta_s, \phi_s; \theta_r, \phi_r)$$

can be defined as the scattering contribution of a surface element $dA = dx\ dy$ illuminated from direction (θ_s, ϕ_s) located at $(x, y, z = z_0)$ into the line-of-sight direction of the observer (θ_r, ϕ_r) looking at point (x_0, y_0, z_0).

Atmospheric Point Spread Function





Geometry for computing the point spread function.

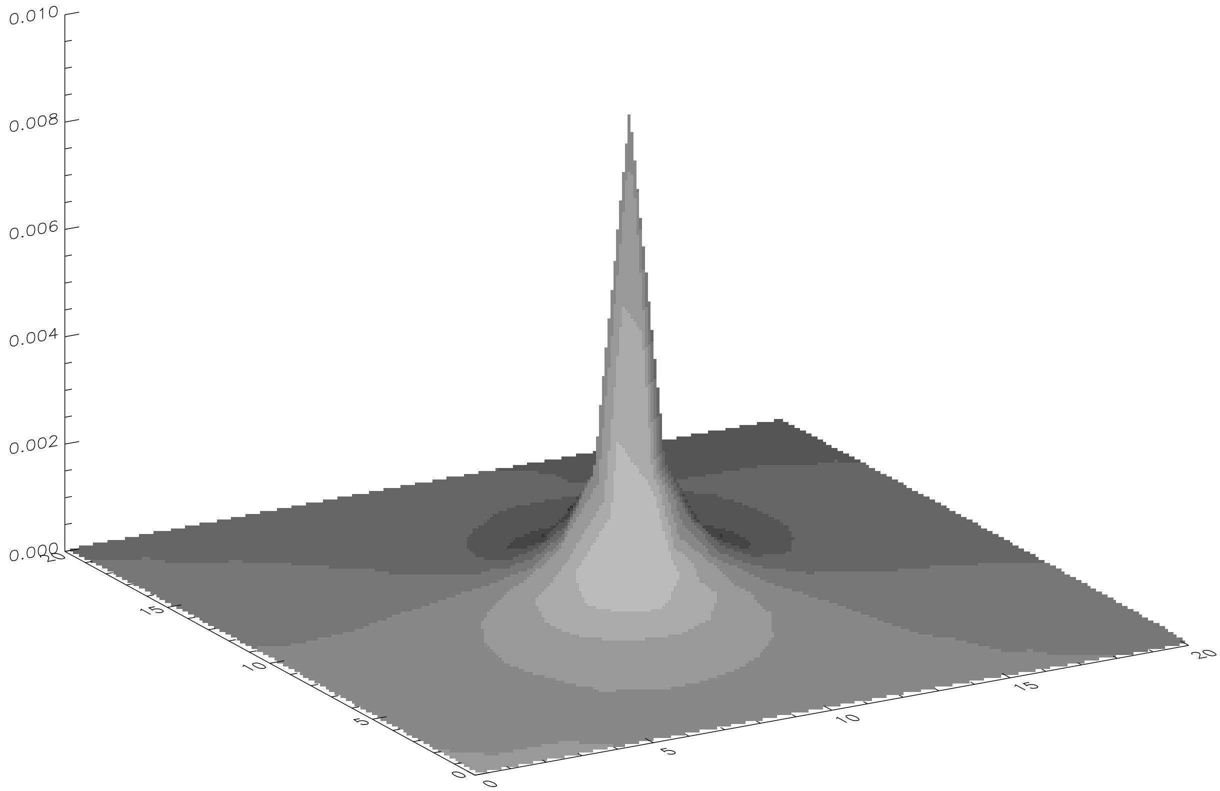
PSF Calculation Using the Extended Radiosity Method

$$PSF(x, y, \ldots) = \frac{\kappa_s\ \Delta l}{4\ \pi} \sum_{k=1}^{K} \frac{\tau(r_k)\ \cos\theta_{r,k}\ f(\theta_{p,k})\ dA}{\pi\ r_k^2} \cdot \exp(-\kappa_t\ (K-k)\ \Delta l),$$

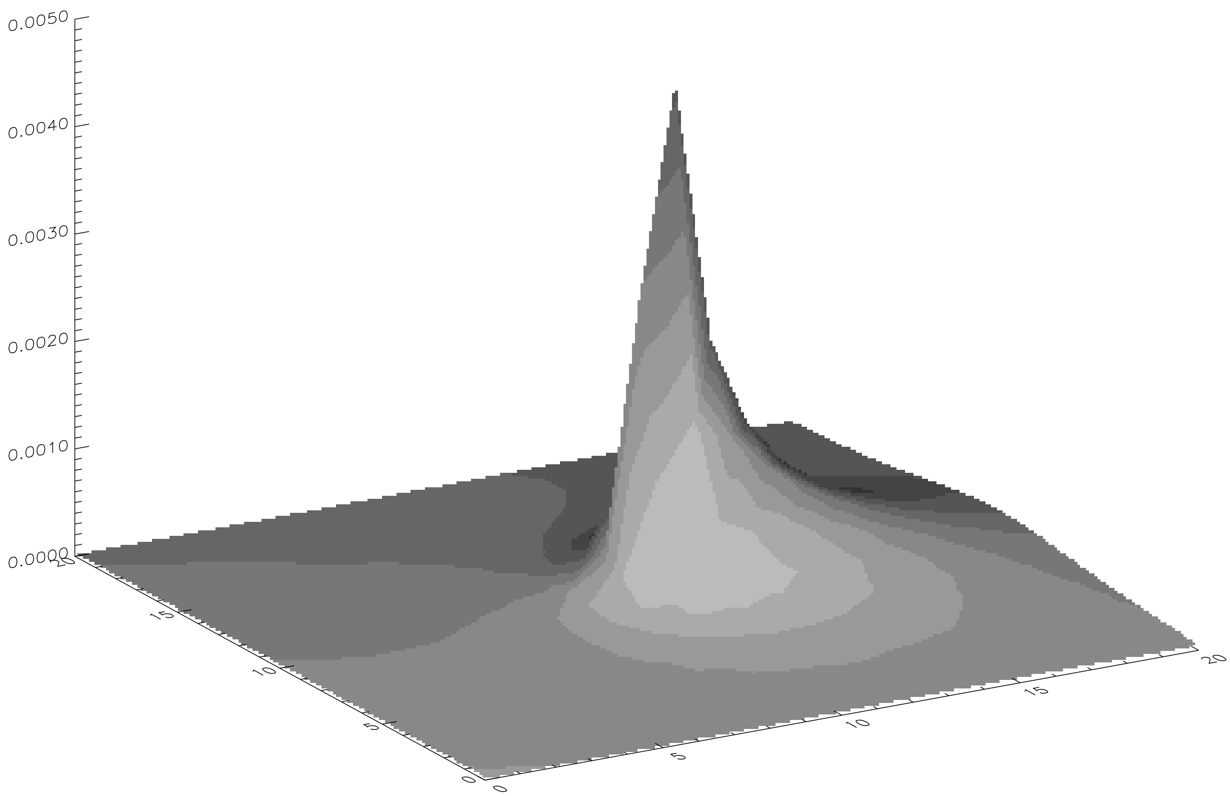
where

- κ_s is the scattering coefficient in $[m^{-1}]$,
- $\Delta l = L_z/(K \cos\theta_r)$,
- L_z is the height of the scattering atmosphere,
- K is the number of layers in the atmosphere,
- $\tau(r_k) = \exp(-\kappa_t r_k)$,
- κ_t is the total scattering coefficient in $[m^{-1}]$,
- r_k is the distance between surface point $\vec{P}$ and a point $\vec{P}_k$ on the line-of-sight in the k-th layer,
- $\theta_{r,k}$ the view zenith angle to dA,
- $f(\theta_{p,k})$ is the scattering phase function of the k-th layer and
- $\theta_{p,k}$ is the scattering phase angle.

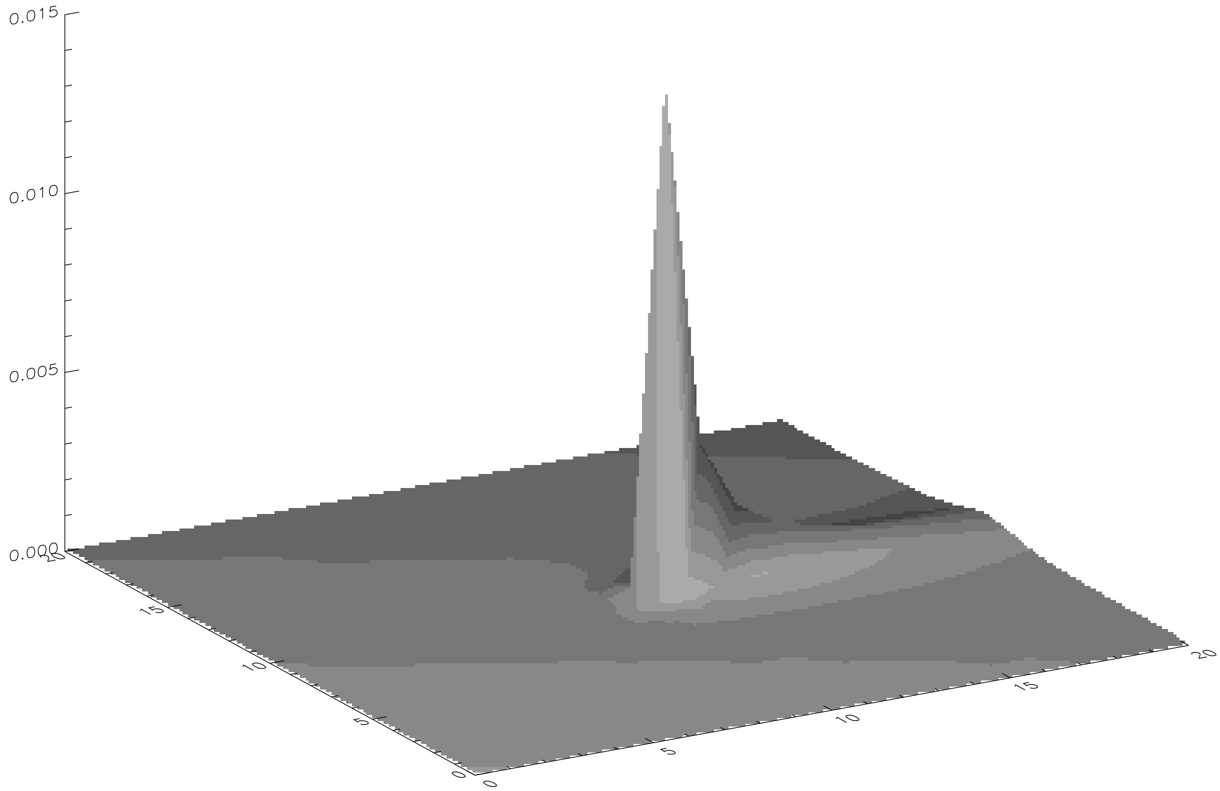
Note : This method takes height dependent scattering and absorption coefficients and even height dependent scattering phase functions into account.



PSF for Lambertian surface and nadir view ($\theta_r = 0,\ \kappa_a = 0.3,\ \kappa_t = 0.8$)



PSF for Lambertian surface and oblique view ($\theta_r = 30^0$, $\kappa_a = 0.3$, $\kappa_t = 0.8$)



PSF for Lambertian surface and oblique view ($\theta_r = 70^0,\ \kappa_a = 0.3,\ \kappa_t = 0.8$)

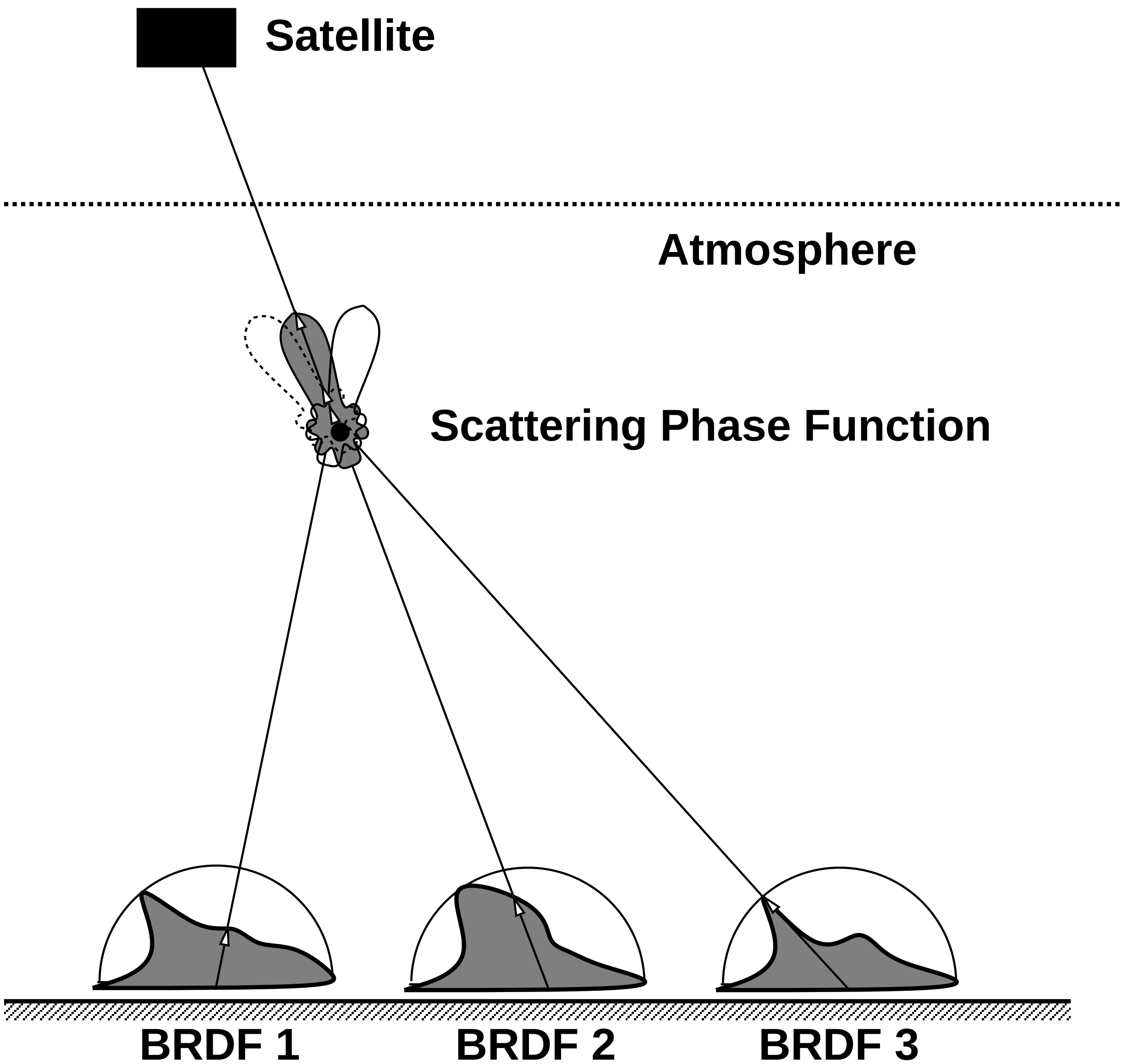
Measured Radiance at the Sensor for Lambertian Surfaces

$$I_{measured}(x, y, \ldots) = \frac{E_0}{\pi}\tau_s\left[\tau_r\rho(x_0, y_0) + \rho(x, y) \otimes PSF(x, y, \ldots)\right] + \\ + I_{path}$$

where

- E_0 is the direct energy incident from the sun in $[W\ m^{-2}]$,
- $\tau_s = \exp(-\kappa_t L z / \cos\theta_s)$,
- $\tau_r = \exp(-\kappa_t L z / \cos\theta_r)$,
- $\rho(x, y)$ is the reflectance at point (x, y),
- $\otimes$ denotes the convolution and
- I_{path} is the path radiance or radiance due to scattering in the atmosphere.

"Real'' Atmospheric Point Spread Function



The Point Spread Function for Non-Lambertian Surfaces

Assumptions :

1. Whole surface has the same BRDF or :

$$f(x, y; \theta_s, \phi_s; \theta_r, \phi_r) = f(\theta_s, \phi_s; \theta_r, \phi_r).$$

2. Contributions from indirect skylight are negligible on the radiance in direction $(\theta_{r,k}, \phi_{r,k})$ or that the upwelling radiance I_{ground} at the ground level is proportional to $f(\theta_s, \phi_s; \theta_r, \phi_r)$.

PSF for non-Lambertian surfaces :

$$PSF(x, y, \ldots) = \frac{\kappa_s\ \Delta l}{4\ \pi} \sum_{k=1}^{K} \frac{\tau(r_k)\ f(\theta_s, \phi_s; \theta_{r,k}, \phi_{r,k}) \cos\theta_{r,k}\ f(\theta_{p,k})\ dA}{r_k^2} \cdot \exp(-\kappa_t (K - k) \Delta l),$$

where $\phi_{r,k}$ is the view azimuth angle of surface dA from point $\vec{P}_k$.

Simulation of Scenes with Heterogeneous Surface Cover

Algorithm :

1. For each surface BRDF $f_i(\theta_s, \phi_s; \theta_r, \phi_r)$, $i = 1, 2, \ldots, N$ compute the point spread function $PSF_i(x, y, \ldots)$.

2. Generate a binary image $Q_i(x, y)$ for each surface type i, where $Q_i(x, y) = 1$ if the point (x, y) has surface cover type i and 0 otherwise.

3. Convolve each image $Q_i(x, y)$ with its point spread function PSF_i $(x, y, \ldots)$.

The measured radiance image is then given by :

$$
\begin{aligned}
I_{measured}(x, y) \quad &= \quad \frac{E_0}{\pi}\tau_s \sum_{i=1}^{N} \Big[\tau_r Q_i(x_0, y_0) f_i(\theta_s, \phi_s; \theta_r, \phi_r) \; + \\
&\quad + \; Q_i(x, y) \otimes PSF_i(x, y, \ldots) \Big] \; + \; I_{path}.
\end{aligned}
$$

Interpretation :

The adjacency blurring effect is the superposition of ground cover type images convolved with their corresponding point spread functions.

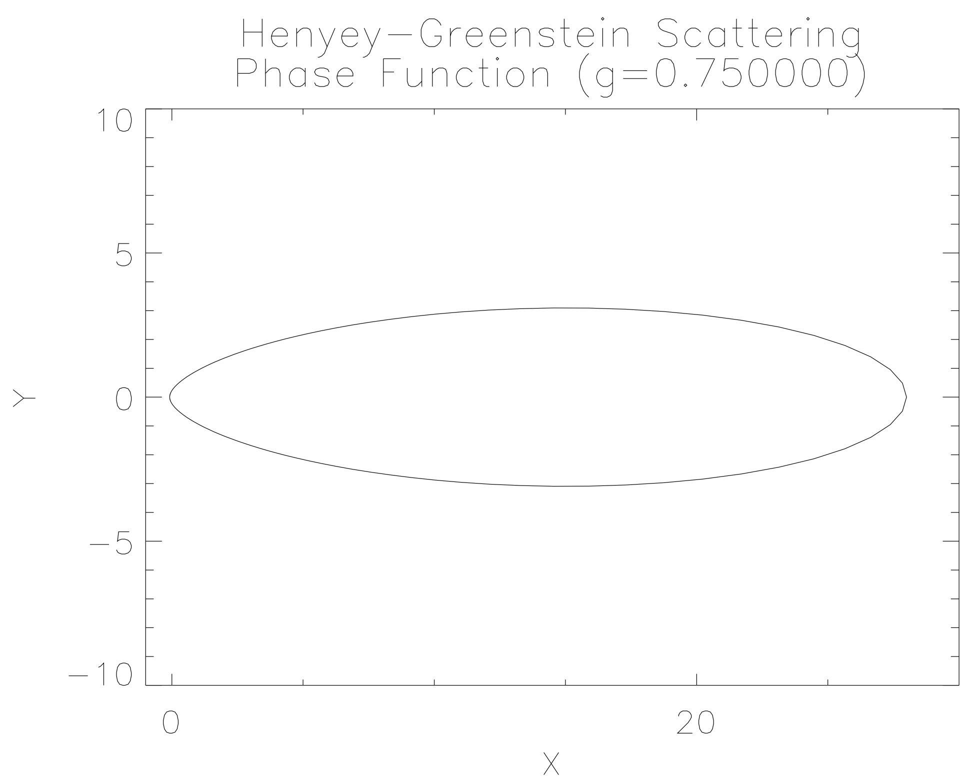
Example of a Surface with Bare Soil, Vegetation and Water

Atmosphere Model :

A "hazy" atmosphere using the Henyey-Greenstein phase function :

$$f(\theta_p) = \frac{1 - \Theta^2}{(1 + \Theta^2 - 2\Theta \cos\theta_p)^{3/2}},$$

where $\Theta = 0.75$ is the asymmetry factor, $\kappa_t = 0.8$, $\kappa_a = 0.05$ for an aerosol laden atmosphere of 1000 m height with 20 layers and a surface of 3000 m by 3000 m horizontal extent with 30 by 30 pixels.

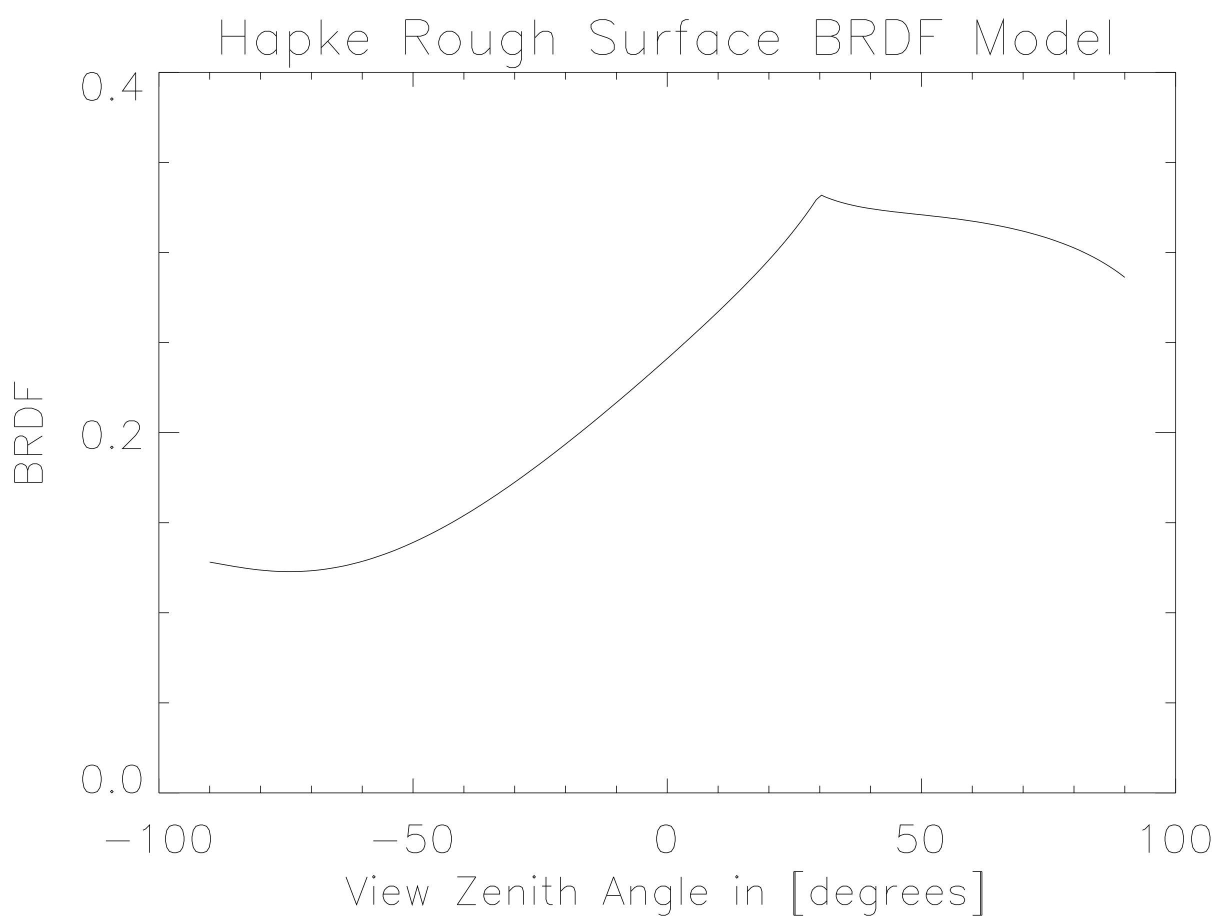


Polar Plot of Henyey-Greenstein Phase Function

Bare Soil BRDF Model (Hapke (1981)) :

$$f(\theta_s, \phi_s; \theta_r, \phi_r) \;=\; \frac{\omega}{4\pi}\frac{1}{\mu_s + \mu_r}\Big[\{1 + B(g)\}P(g) + H(\mu_s)H(\mu_r) - 1\Big],$$

where ω is the average single scattering albedo, $\mu_s = \cos\theta_s$, $\mu_r = \cos\theta_r$, $\cos g = \mu_s\mu_r + \sin\theta_s\ \sin\theta_r\ \cos(\phi_r - \phi_s)$, $B(g) = B_0/[1 + h^{-1}\tan(g/2)]$, $B_0 = S(0)/(\omega P(0))$, $P(g) = 1 + b\cos g + c[(3\cos^2 g - 1)/2]$ and $H(x) = (1 + 2x)/(1 + 2[1-\omega]^{1/2}\ x)$. The BRDF parameters chosen were : $\omega = 0.57$, $S(0) = 0.48$, $h = 0.21$, $b = 0.86$ and $c = 0.7$.

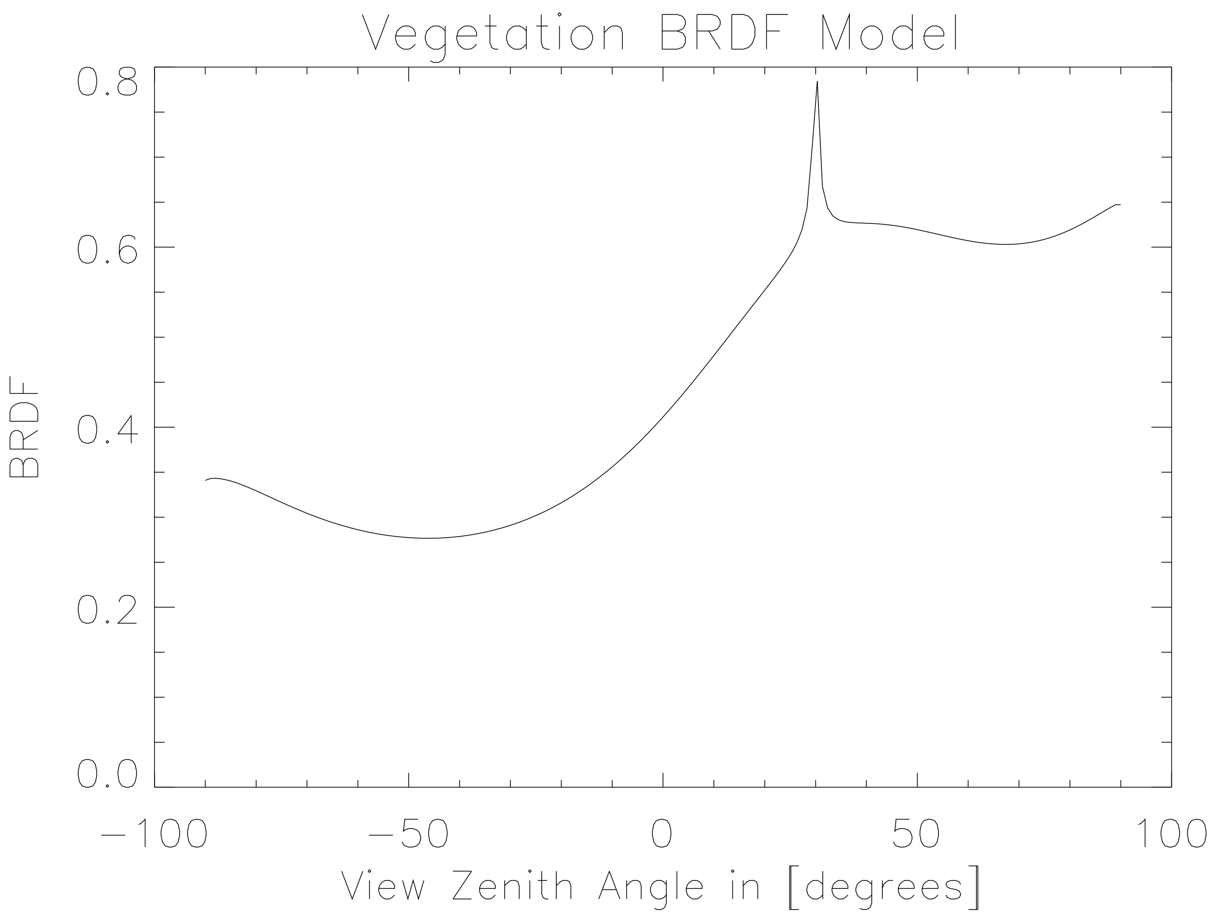


BRDF Slice in the Principal Plane

Vegetation BRDF model (Pinty et al (1990)) :

$$f(\theta_s,\phi_s;\theta_r,\phi_r) \;=\; \frac{\omega}{4\pi}\frac{\nu_s}{\nu_s\mu_s+\nu_r\mu_r}\Big[P_v(g)\;P(g)+H\Big(\frac{\mu_s}{\nu_s}\Big)H\Big(\frac{\mu_r}{\nu_r}\Big)-1\Big],$$

where ν_s and ν_r describe the leaf orientation distribution for the illumination and observation angles which depend on a parameter χ_l with range: $(-0.4 < \chi_l < 0.6)$, $P(g)$ is the leaf scattering phase function which is the Henyey-Greenstein function, the function $P_v(g)$ depends on the variable $G = [\tan^2\theta_s + \tan^2\theta_r - 2\tan\theta_s\tan\theta_r\cos(\phi_s-\phi_r)]^{1/2}$, the radius of sun flecks r in $[m]$ and Λ the leaf area density in $[m^2 m^{-3}]$. We selected the following canopy parameters : $\omega = 0.8$, $\Theta = -0.4$, $\Lambda = 0.01$, $r = 1.$, $\chi_l = 0.2$.

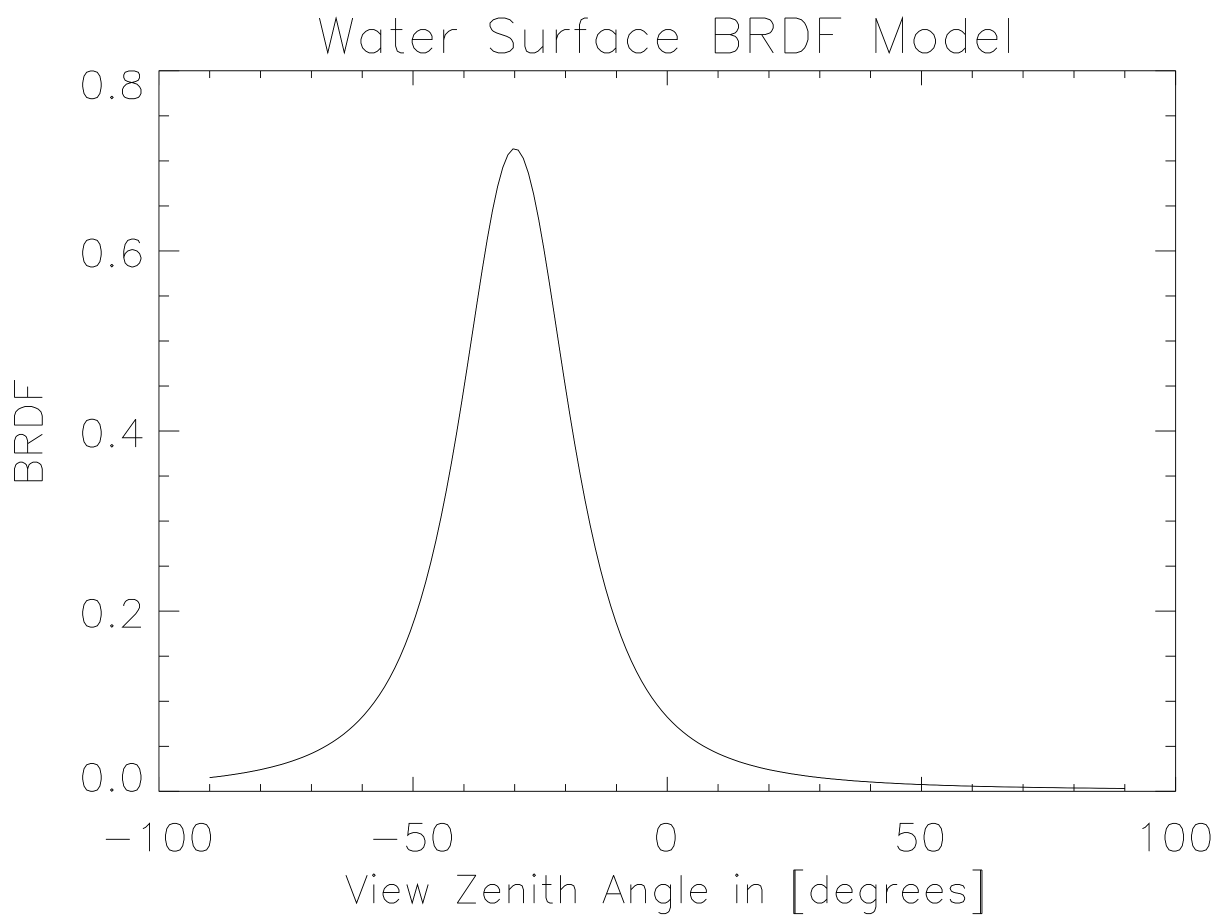


BRDF Slice in the Principal Plane

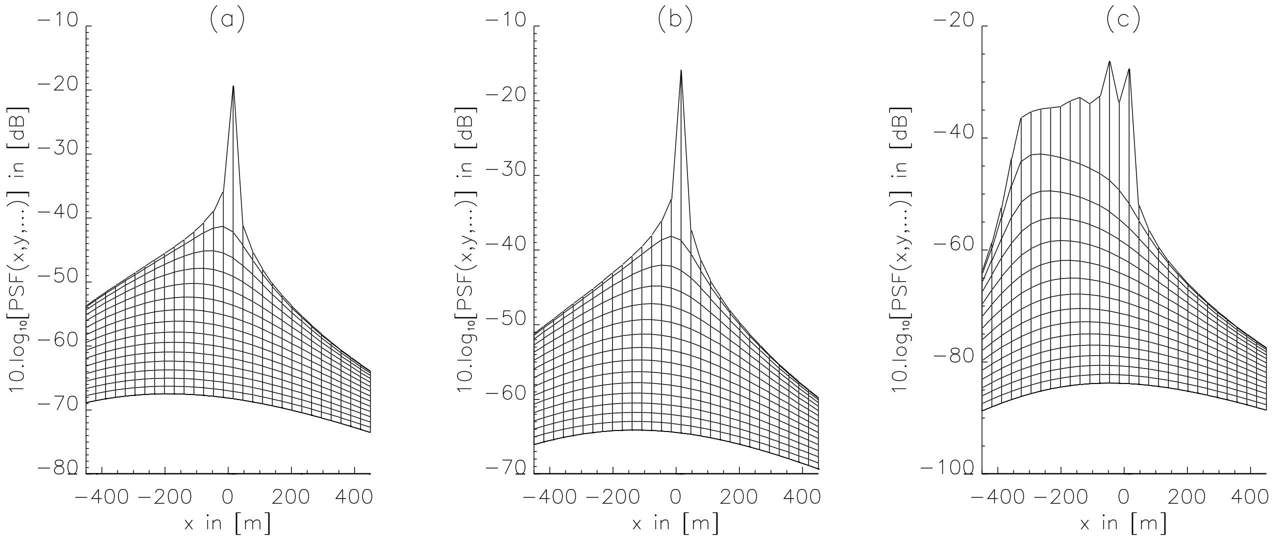
Water surface BRDF model :

$$f(\theta_s, \phi_s; \theta_r, \phi_r) = \rho_{water} P(g)$$

with the forward peak aligned with the specular reflectance direction $(\theta_s, \phi_s + \pi)$ or $g = \cos^{-1}[\mu_s \mu_r + \sin\theta_s \sin\theta_r \cos(\phi_s - \phi_r - \pi)]$. We selected a reflectance ρ_{water} of 2.55 % and an asymmetry factor of $\Theta = 0.95$.

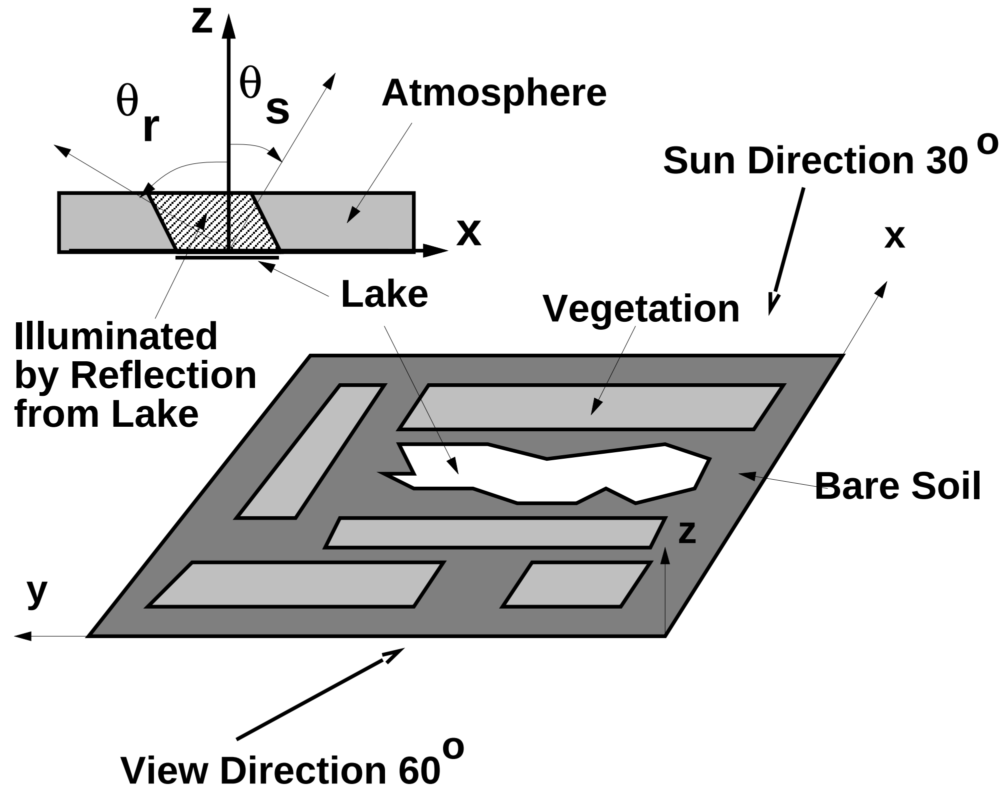


BRDF Slice in the Principal Plane



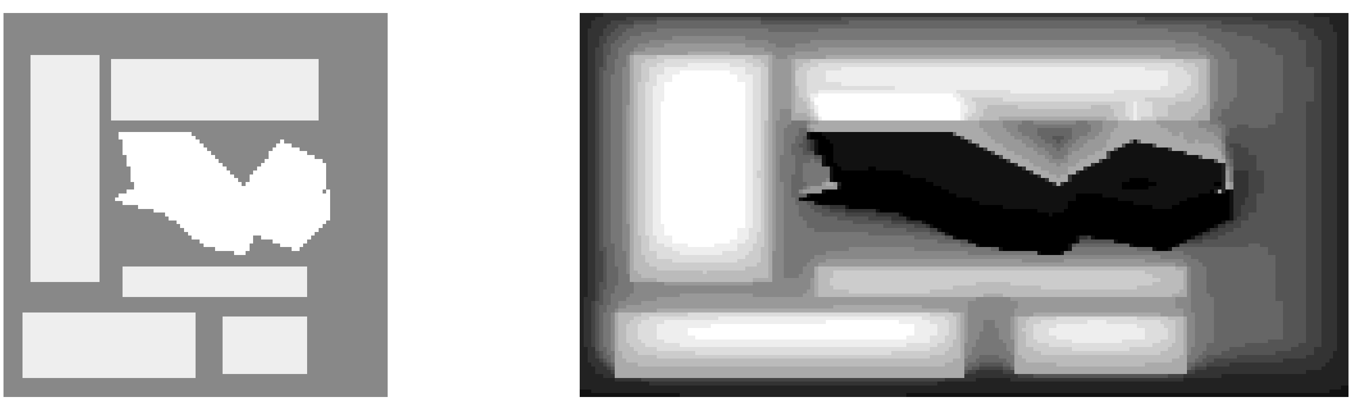
Point spread functions of (a) bare soil, (b) vegetation and (c) water with the z-axis in logarithmic scale and the y-axis points into the paper.

Simulated Scene



Viewing geometry

(a) (b)



Simulated scene from (a) above and (b) viewed through atmosphere from the below at 60^0 view zenith angle and illuminated from above at 30^0 sun zenith angle.

Conclusions

- The extended radiosity method has been used to compute point spread functions for a layered atmosphere above a heterogeneous ground cover.

- The PSF's were found to be asymmetric for non-Lambertian surfaces

- The adjacency blurring effect was simulated for a scene containing vegetated, bare soil and water surfaces.